SINGLE-PHASE INDUCTION MOTOR

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Design of a Single-Phase Induction Motor

A THESIS

PRESENTED BY

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Contents.

INTRODUCTION.

This work is presented with the idea that the design of a split phase motor of large output in relation to size of machine could be accomplished by proper arrangment of parts to bring the greatest possible air circulation in and about those such places as are likely to reach limiting temperatures.

The frame of the machine is built up of castings which are not complex and present an easy job for the machine shop. The bearing surfaces are large insuring long life. Lubrication is by a ring dipping into a bath of oil, dust is kept out of all oil passages by felt washers on the shaft at either end of bearing housing.

CALCULATION.

Part 3.

The circle diagram can be applied to design of a single phase motor, but the operating range comes so near the origin that data to be derived from it are subject to to more error than is permissable, hence the design must attempted by other methods. An analysis of how motor action is produced devolves what is called the quadrature field. It is action between the transformer field and quadrature field that produces rotation. The transformer field arises directly from the line current in the stator winding, while the quadrature field arises only after the motor has come up to speed. As the inductors on the rotor cut the main transformer field currents are induced in them due to the impedance of these paths being nearly all reactance, the currents are in time quadrature with the induced e.m.f. This in turn puts the two fields in time and space quadrature. It will be upon the above asumptions that calculations of design will be made together with certain constants of reliable sources.

CALCULATIONS.

THE AMPERE TURNS FOR THE AIR-GAP.

The expression showing the ampere turns required to send flux across the air-gap as follows

$$AT = .3133Bd$$

Where d is the effective length of air-gap and B is the flux density.

For trial calculation d = .045in.
B = 12000
lines per in

$$AT = .3133 \times 12000 \times .045$$
$$= 169 \text{ per pole.}$$

AMPERE TURNS FOR THE SPEED FIELD.

Theory and practice confirm the fact that at synchronous speed the two fields of a single phase motor are equal. Below synchronous speed the speed field weakens directly as as the speed. Because of the small slip of these machines for figuring the two will be assumed equal.

Hence AT total for the air-gap.

$$= 169 \times 2 = 338 \text{ per pole.}$$

CALCULATIONS.

AMPERE TURNS FOR THE TEETH.

The reluctance of the teeth is a small percentage of the total magnetic circuit and because of the low flux density it is not likely that tooth density will approach saturation. In case any large percentage of the air-gap flux traversed the slots then the ampere turns for this part of the magnetic would have to be taken into account. So that for trial not attempt will be made to ascertain this part.

AMPERE TURNS FOR THE YOKE.

This also is a very small part of the total reluctance of the magnetic circuit and will be neglected as always more material is put into this part of the machine for mechanical strength than would be required for electrical purposes. And as many previous designs bear out this fact it not considered essential that it be proven.

CALCULATIONS

FACTOR FOR DISTRIBUTED WINDING

At this point it will become necessary to decide the number of slots in the stator laminations. The accompanying drawing shows a satisfactory pattern which can be purchased, all dimensions being given on the drawing.

There being 32 slots the winding can be arranged in pyramid form in four pairs of slots per pole. The factor [illegible] to give sinusoidal distribution of air-gap flux is .655*.

The total ampere turns [illegible] full pitch winding will have to be increased as given by the following equation:

$$AT\ total = \frac{360}{.655}\ 552\ \text{per pole}$$

The accompanying drawing, Fig. 2, shows the graphical method of determining the winding turns for each pair of slots. Results are tabulated below.

*Gray's Electrical Machine Design.

CALCULATIONS

RUNNING COILS

Since slots are 7/16" x $\frac{3}{4}$" this area will accomodate 24 turns of #14 D. C. magnet wire. But to insure less crowding of conductors and lessen the danger of insulation breakdown #15 D. C. wire will be used for the running winding.

STARTING COILS

In the space left in pairs of slots No. 3 and No. 4, is placed the starting coils. It is desirable to have as much phase displacement as possible, and as the current in the starting winding will be of low power factor at the start, the remaining choice is to have the current of the starting winding near unity power factor. By having a preponderance of resistance to the starting winding, the effect of a rotating field will be had.

[illegible]

WINDING DATA

RUNNING COILS. Total [illegible], [illegible]
#15 B.S.d.c.

1st slot-------10 turns
2nd slot-------25 turns
3rd slot-------25 turns
4th slot-------15 turns

Starting coils total turns, 150
#20 B.S.d.c.

2nd slot-------[illegible] turns
3rd slot-------[illegible] turns

TOTAL EXCITING CURRENT

T = [illegible]

I = 7.[illegible] amp.

CALCULATIONS

ROTOR

Diameter of rotor space 6 in. Length of core 5 in. The torque to be developed is figured from the horse power output.

$$H.P. = \frac{6.28 \times T \times [illegible]}{33000} \; N \; 1750$$

The rotor pattern is also shown in Fig. 2. The force at center line of rotor bars is found to be 16 pounds.

The force acting on an inductor carrying current in a field of strength B is

$$F = Bli$$

$$16 \times 980 \times 453 \quad 6000 \times 12 \times 6 \; \frac{i}{10}$$

$$i = [illegible]$$

[illegible]

Flux density of speed field

$$[illegible] \frac{[illegible]}{A} = 12000 \times \frac{10}{15}$$

CALCULATIONS

E. M. F. equation for quadrature field inductors as follows:

$$v. = BlV \qquad V = \text{peripheral speed}$$

$$= 12000 \times 6 \times 800 \times 10^{-8}$$

$$= .575 \text{ volts}$$

Resistance of quadrature field circuit per pole

$$\frac{E}{I} = \frac{.575}{150} = .005 \text{ Ohms}$$

SIZE AND NUMBER OF ROTOR BARS

The power developed by the machine is in large part dependent on the rotor. Being of the squirrel cage type e.m.f.'s, induced in the rotor conductors are small and in order to make the quadrature field as large as possible a low resistance [illegible].

[illegible]

Length of quadrature field circuit is figured as follows. Diameter of rotor, 5 in. length of core 6 in. quarter circumference of rotor inductor circuit

$$\frac{3.14 \times 5}{4} = 4$$

$$2 \times 4 + 2 \times 6 = 20$$

$$R = K \frac{L}{A}$$

For copper K = 10.6

A in circular mils

L in inches.

Since brass and solder enter into the circuit the value of K will be increased to 14.0

[illegible] = 14 [illegible] $\frac{20}{A}$

A = 70000

This is a conductor whose cross section is one half inch in diameter. From Fig. 2 it will be seen that only 4 inductors per pole have an induced voltage due to rotation, therefore the cross section of the [illegible] field circuit will be subdivided into 4 parts, making the cross section per inductor .077

[illegible]

[illegible] to increase the area as always calculated, because in distributing the quadrature field circuit in 2 pair of slots, the e.m.f.'s inducted will not be equal.

The size of rotor inductor will be as finally determined

$$\frac{.[illegible]}{.65} = .091$$

This area will be increased to .11 sq. in. This oversize to the rotor bars provides for overload. These three-eighths bars are rolled flat till the thickness between parallel faces is seven thirty-seconds of an inch. These are also set endwise in the rotor slots as shown in Fig. 2 and not [illegible].

*Behrend: Elec. Mach. Design.

LOSSES

CORE LOSSES

The core loss from curves of frequency and flux density will be about .5 watts per pound weight of laminated iron.

Weight of laminated iron = 45 lbs.

.5x45 = 22.5 watts

FRICTION AND WINDAGE LOSSES

From data obtained from previous designs this loss is taken as to [illegible] 50.

COPPER LOSSES. (Stator)

Two pounds of [illegible] wire will be required for the winding of the stator, the resistance of which will be .75 ohms. With full load current of 11 amperes copper loss and the stator will be 90.5 watts.

[illegible]

COPPER LOSSES (Rotor)

The current to excite the quadrature field in the rotor forms a constant loss, so that as roughly estimated will be

$$[illegible]^2 \times .0014$$

$$56000 \times .0014 = 50 \text{ Watts}$$

Due to increased size of rotor inductors, the resistances will vary inversely as the cross sections. The constant .003 is reduced to .0014 as follows:

$$\frac{.165}{.077} = \frac{.003}{.0014}$$

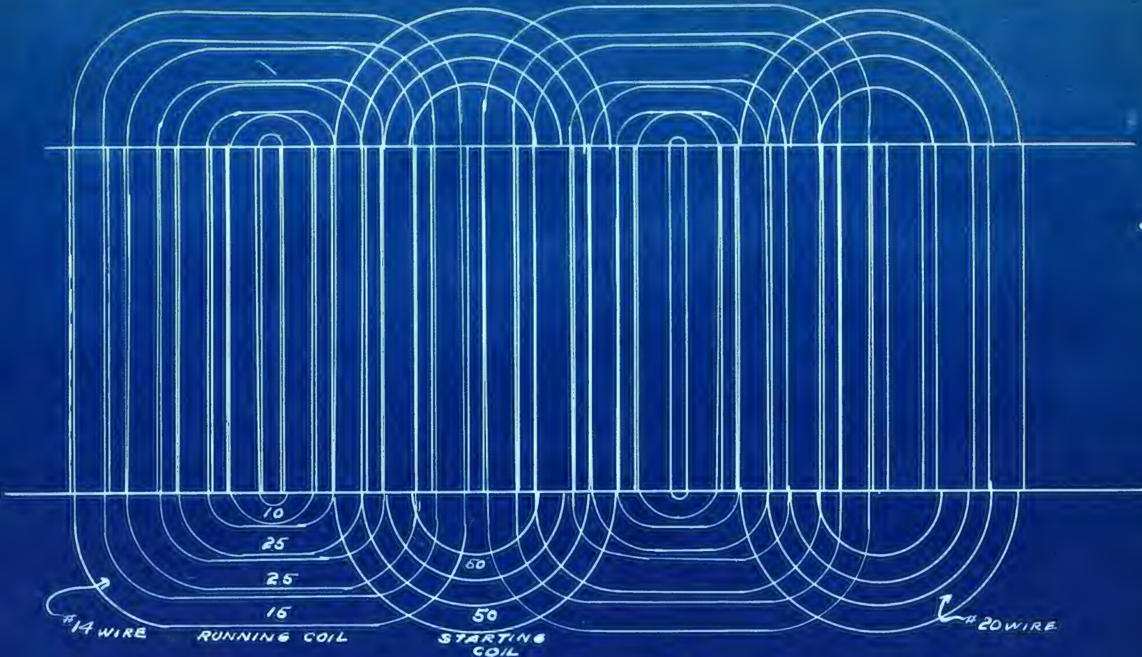
.165 = final area of quadrature circuit.

The current set up in the rotor due to transformer action is small in this machine due to its small slip and will be roughly estimated as equal to the quadrature field loss.

Total rotor copper loss	100 Watts
Total copper losses	190.5 "
Friction and windage loss	20 "
Iron losses	22.5 "
TOTAL LOSSES	232.5 "

DESIGN SHEET

DIMENSION.	CALCULATED VALUE	VALUE AS FINALLY DETERMINED
Nº OF POLES	4	4
SPEED r.p.m.	1750	1750
VOLTAGE	110	108
OUTSIDE DIA. STATOR	8"	8"
INSIDE DIA "	5"	5"
SIZE SLOTS	3/8" x 3/4"	7/16 x 3/4"
SLOT OPENING	1/8"	1/8"
Nº OF SLOTS	32	32
OUTSIDE DIA. ROTOR	5"-.050"	5"-.030"
DIA. ROTOR SPIDER	2"	2"
SIZE ROTOR SLOTS	3/8" D	7/32" x 1/2"
SLOT OPENING	1/16"	1/16"
Nº OF SLOTS	32	39
LENGTH OF STATOR	3"	2.5"
LENGTH OF ROTOR	3"	2.75"
SIZE ROTOR BARS	5/16" D	7/32" x 1/2"
END RINGS		BRASS
END RING THICKNESS	1/8"	1/4
RUNNING COILS		
SIZE WIRE	16	15
Nº OF TURNS	90	75
1ST SLOT	10	10
2ND "		25
3RD "		25
4TH "		15
STARTING COILS		
SIZE WIRE		20
Nº OF TURNS		150
2ND SLOT		60
3RD SLOT		90



WINDING DIAGRAM SHOWING STARTING AND RUNNING COILS
WINDING ARRANGED IN FOUR PAIRS OF SLOTS
FIG. 1

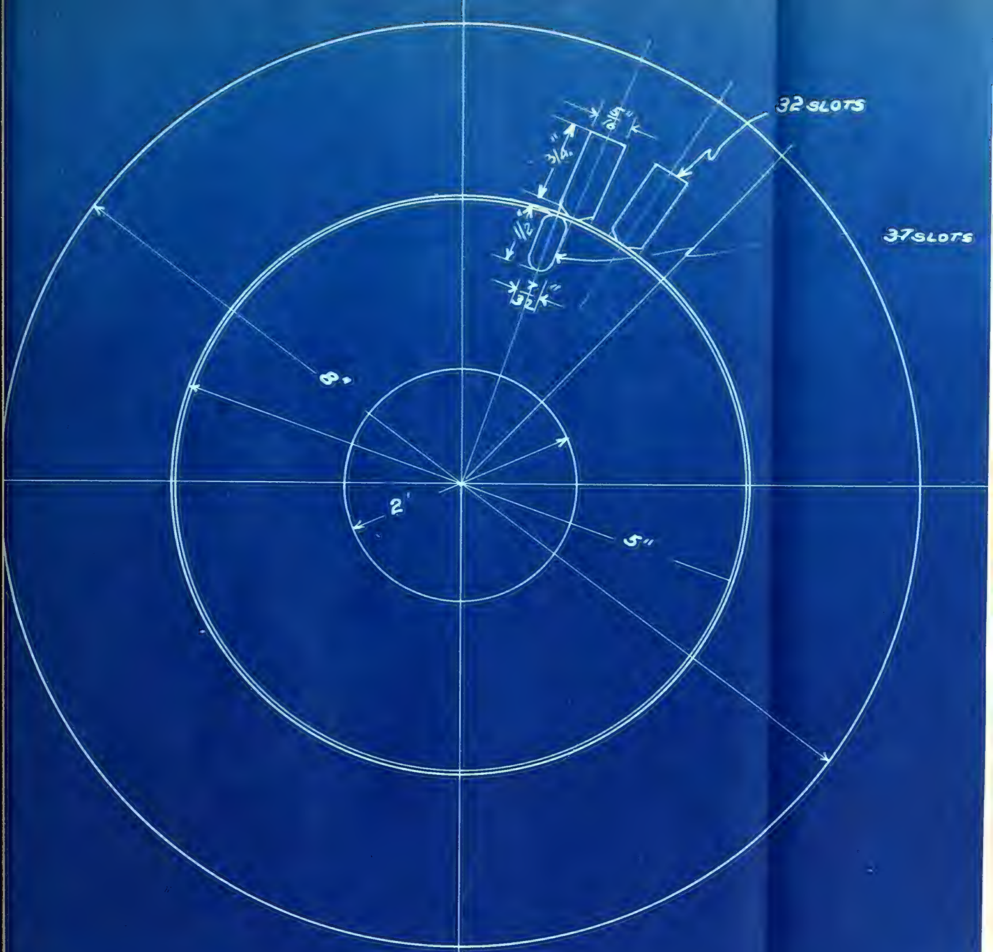
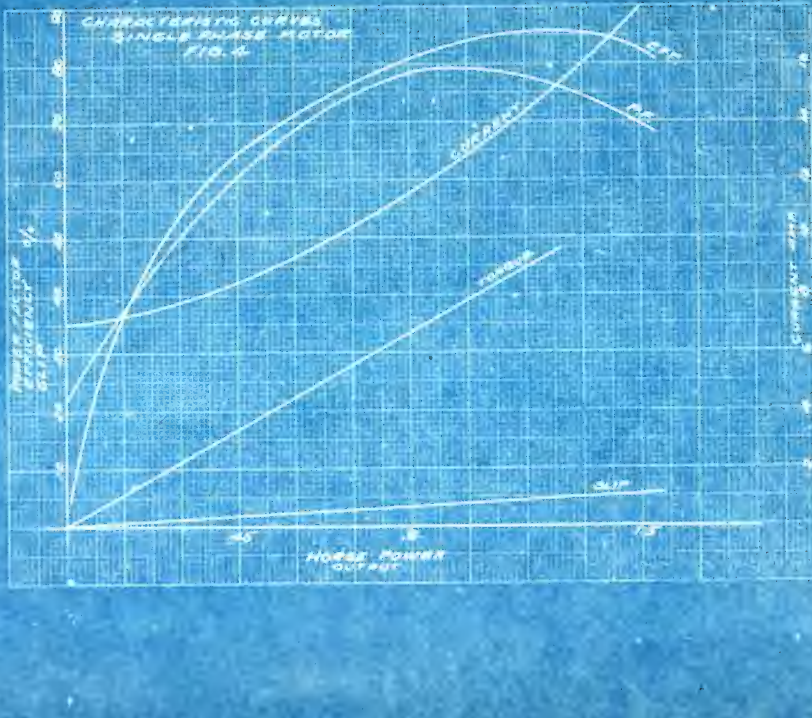


FIG. 2

SINGLE PHASE MOTOR   NO LOAD TEST

VOLTS	AMP.	WATTS IMPUT	POWER FACTOR	VOLT AMP	FRICTION LOSS WATTS	Fe AND I_s LOSS	PRIMARY I^2R LOSS
118	8	250	.265	944	21	165	64
108	7.	200	.265	756	21	130	49
100	6.3	155	.246	630	21	94.5	39.5
91	5.7	140	.270	518	21	87.5	32.5
82	5.	100	.244	410	21	54.	25
58	3.5	50	.246	203	21	17.2	12.2
30	2.0	25	.415	60	21	0	4

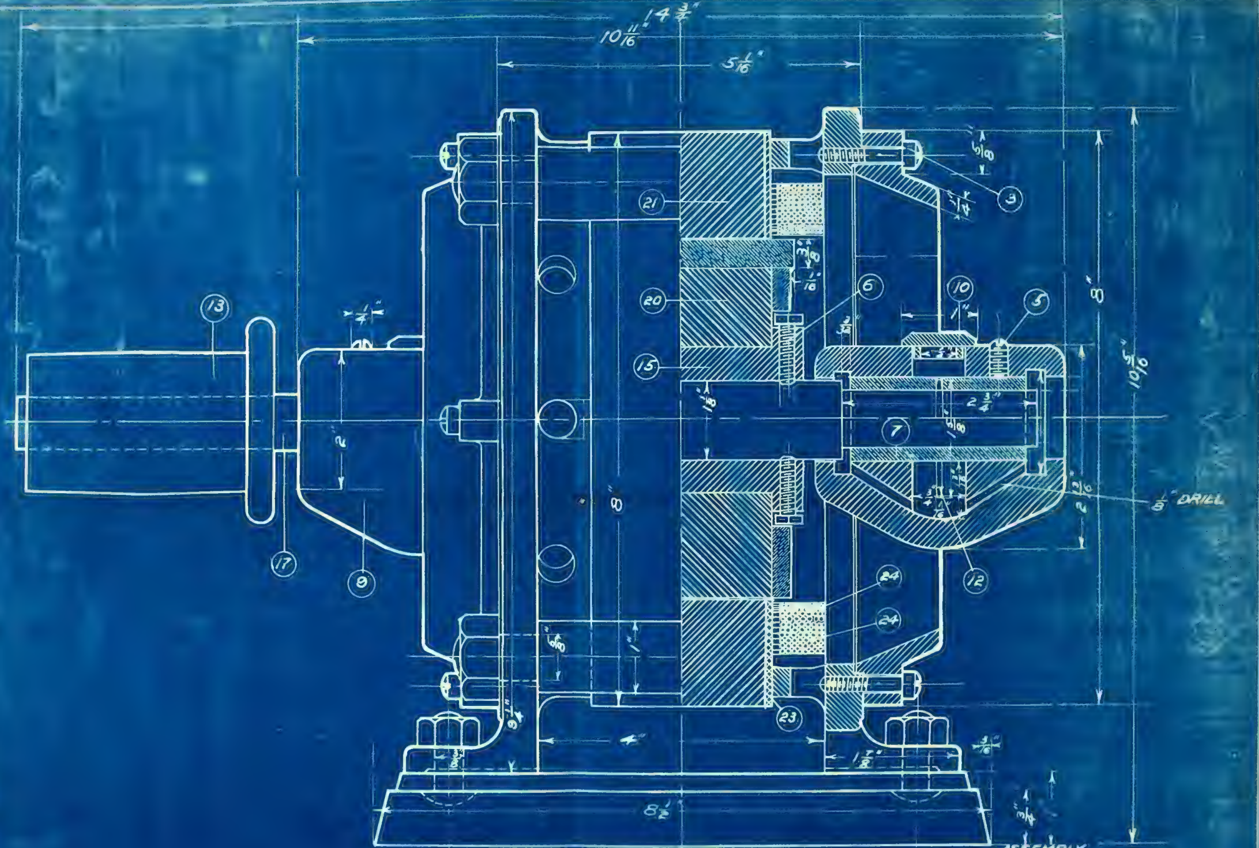
FIG. 3


CHARACTERISTIC CURVES
SINGLE PHASE MOTOR
FIG. 4
CURRENT
TORQUE
SLIP
HORSE POWER
OUTPUT
POWER FACTOR
EFFICIENCY
SLIP
%

Single Phase Motor Prony Brake Test

Torque	Amperes	Volts	Kilowatts	Horse Power	R.P.M.	Power Factor	Eff. %
0	7.5	109	.21	000	1800	.247	0
.125	7.6	109	.215	.0415	1790	.260	14.7
.318	7.6	109	.25	.104	1780	.301	31.0
.875	8.0	108	.4	.285	1770	.464	53.2
1.87	9.2	108	.67	.61	1760	.675	68.0
2.93	11.14	108	.97	.95	1750	.785	73.0
3.95	14.1	107.5	1.2	1.27	1735	.780	78.0
4.98	18.0	107.	1.35	1.50	1700	.70	82.5

FIG. 5



ASSEMBLY

ALTERNATING CURRENT MOTOR

ARMOUR INSTITUTE OF TECHNOLOGY

SCALE 12" = 1 FT

MAY 31 1917 CHICAGO, ILL.

DRAWN BY Chas. F. Holmes

CHECKED BY

PLATE # 1

BILL OF MATERIAL

MARK	NAME	M'T'L	W'TED	REMARKS
1	FRAME BOLT	STEEL	4	5/8" U.S. ST'D
2	FR. BOLT NUT	"	8	5/8" U.S. ST'D
3	FILISTER H'D SC'W	"	8	1/4" U.S. ST'D
4	CARRIAGE BOLT	"	4	3/8" U.S. ST'D
5	SET SCREWS	"	3	H'DED 1/4" x 16 TH
6	SQ. H'D SET SCREW	"	2	H'DED 1/4" x 16 TH
7	BUSHING	BR'NZE	2	"NON GRAN"
8	CASTING (FRAME)	C.I.	2	
9	CASTING (BEAR'G)	C.I.	2	
10	OIL HOLE COVER	C.I.	2	FINISHED
11	SLOTTED BASE	C.I.	1	IN ROUGH
12	OIL RING	STEEL	2	FINISHED
13	PULLEY	C.I.	1	FINISHED 2" x 3"
14	END RINGS	BR'SS	2	
15	ROTOR SPIDER	C.I.	1	FINISHED
16	SPIDER NUT	STEEL	1	2" x 16 THREAD
17	SHAFT	"	1	
18	BUSHING	RUBB'R	4	1/8" PIPE TH'D
19	ROTOR BARS	COPP'R	37	#2 FLAT WIRE
20	ROTOR SHEET	STEEL	200	.014" THICKNESS
21	STATOR SHEET	"	"	.014" THICKNESS
22	HEX. NUT	"	4	3/8" U.S. ST'D
23	FIBRE RINGS	FIBRE	2	SAME AS STATOR
24	MAGNET WIRE	COPP'R	#15, #28	4 LBS AND 1 LB
25	LEAD WIRES	"		10 FT #12

ASSEMBLY
ALTERNATING CURRENT MOTOR
ARMOUR INSTITUTE OF TECHNOLOGY
SCALE 12" = 1 FT
MAY 31 1817
CHICAGO, ILL.
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PLATE #2

ASSEMBLY

ALTERNATING CURRENT MOTOR

ARMOUR INSTITUTE OF TECHNOLOGY

SCALE 12" = 1 FT.

MAY 31 1917
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CHICAGO ILL
Chas. F. Holmes

PLATE 8